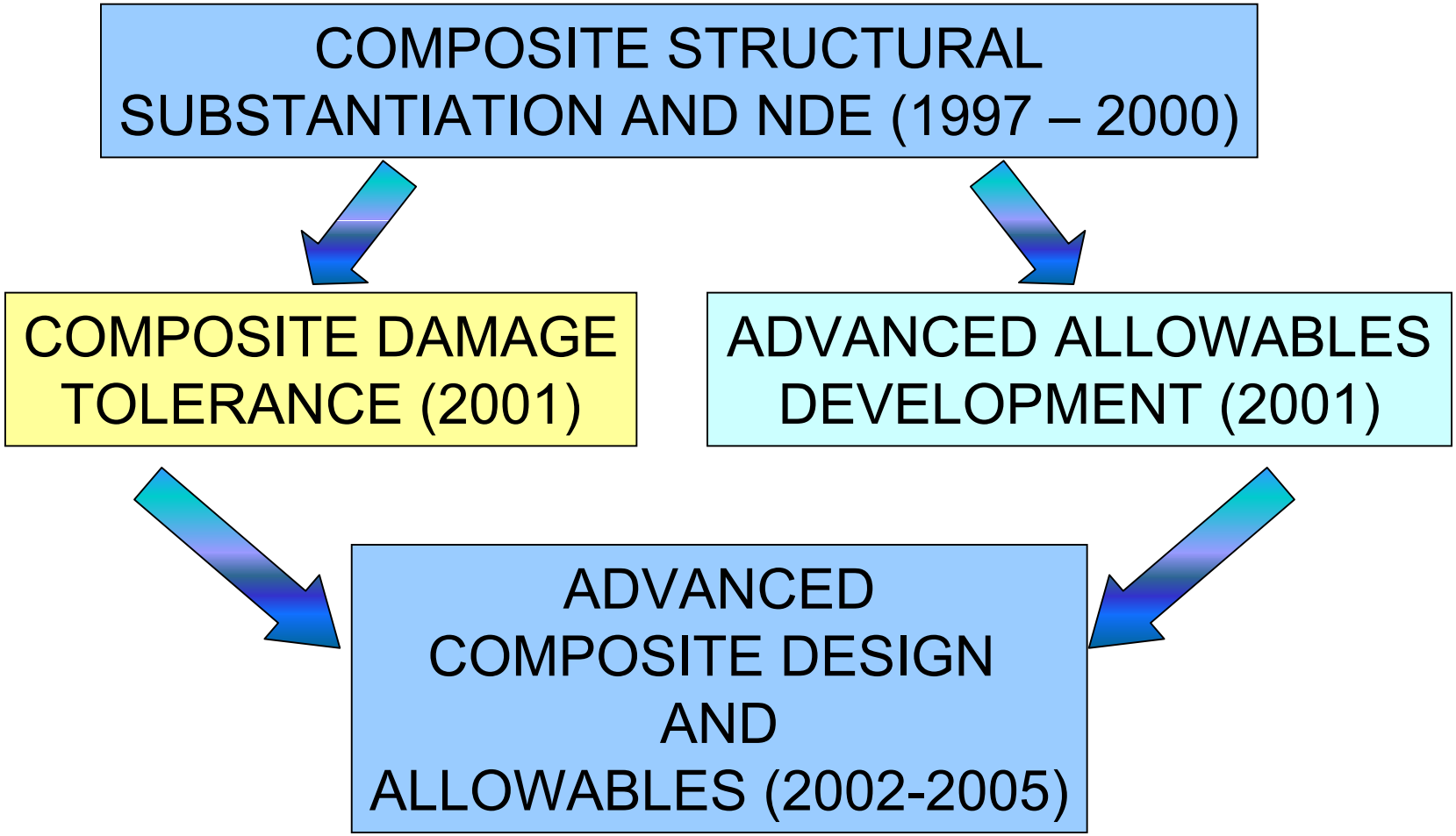
NRTC/CRI
ADVANCED COMPOSITE DESIGN AND ALLOWABLES

Xiaoming Li - PI

Bell Helicopter

NRTC/CRI COMPOSITE MATERIAL PROGRAM HISTORY AT BELL



ACDA OBJECTIVE:

TO REDUCE THE COST AND CYCLE TIME FOR DEVELOPMENT OF STRUCTURAL DESIGNS

Strategies

Reduce testing cost by developing

(1) standard test methods and design allowables usage guidance

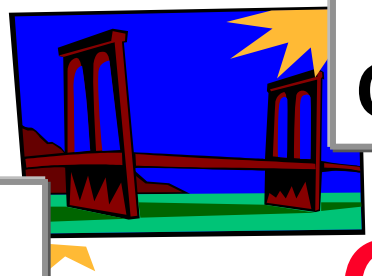
(2) analysis and simulation methods for rotorcraft composite materials and structures.

ACDA ACTIVITIES

- Test Development And Structural Usage Allowables Guidance Activities
- Electronic Database Framework For CRI Member "Data Sharing"
- FEM Based Fatigue Delamination Onset/growth Life Methods
- Extreme Environmental Effects On Composite Materials
- "Virtual Testing" Analytical Methodologies for Crashworthiness Analysis

How do These Relate to the Certification Process?

FAA D&DT Certification Process

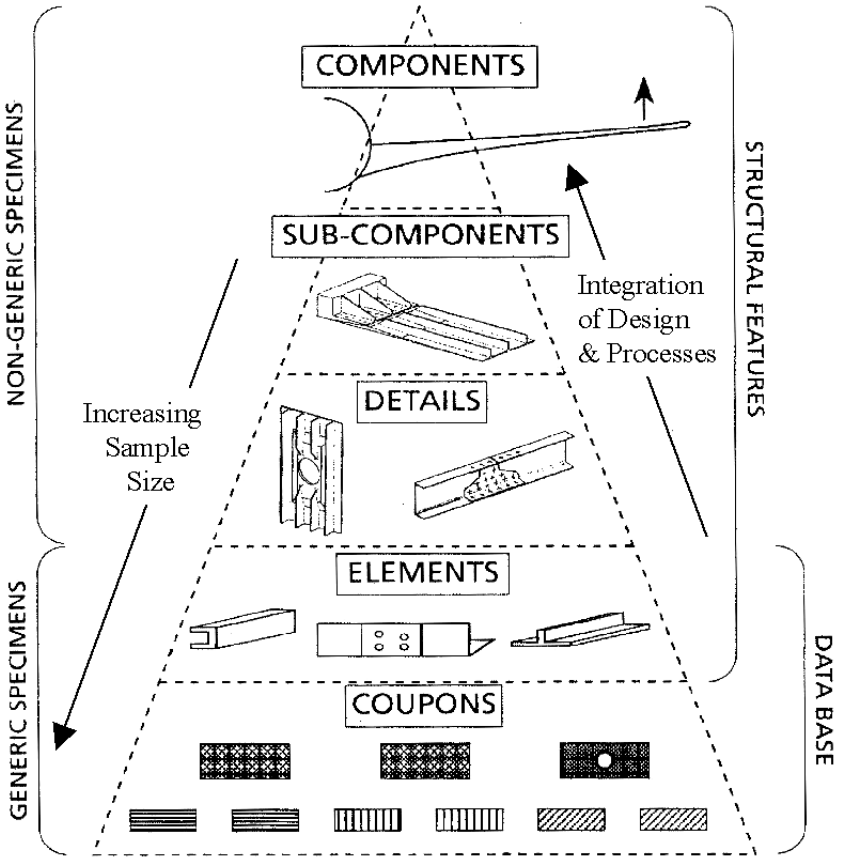


NRTC/CRI ACDA Research

?

"BUILDING BLOCK" STATIC STENGTH SUBSTANTIATION OF COMPOSITE AIRCRAFT STRUCTURE

ACDA PROGRAM



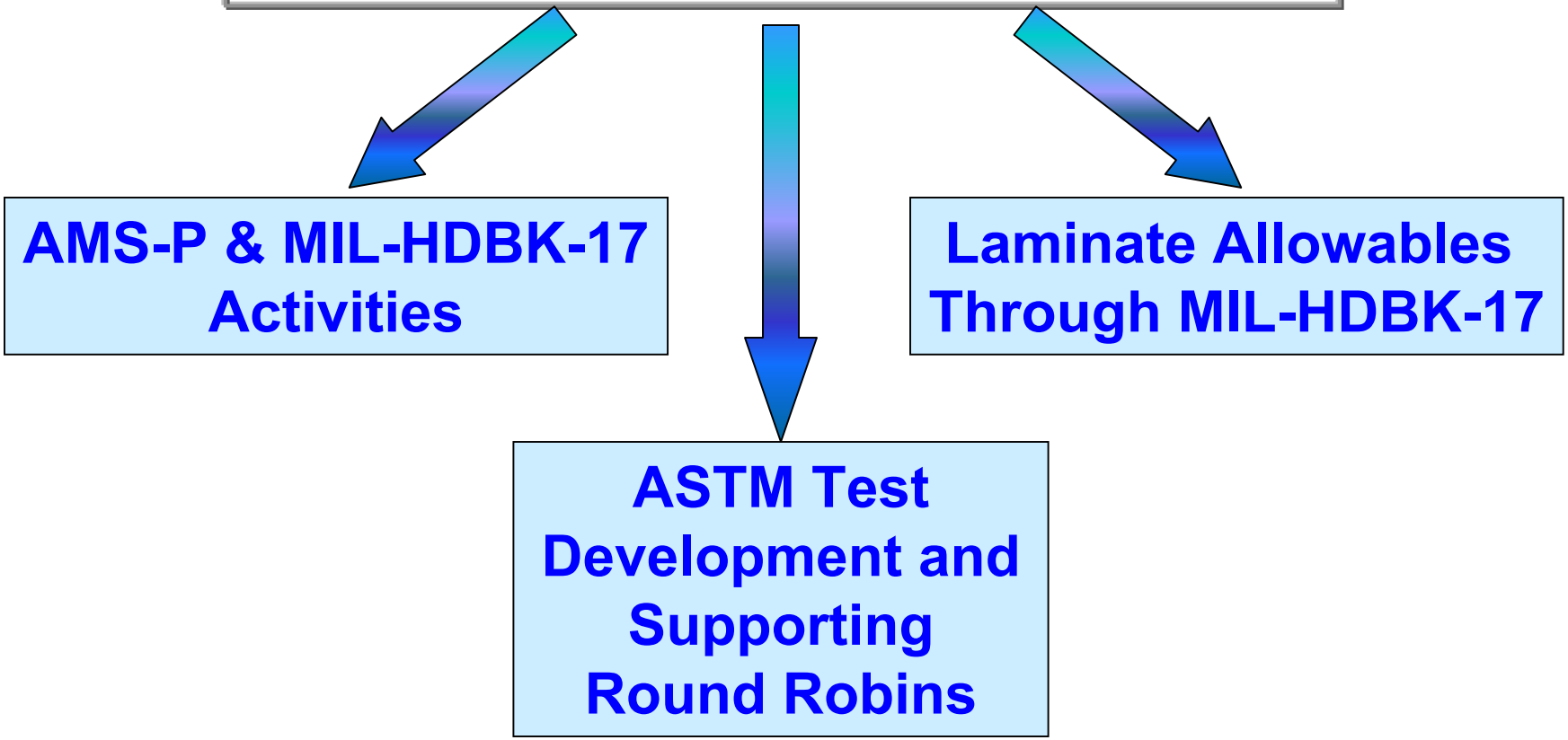
Reference: Rouchon, J., "Certification of Large Aircraft Composite Structures, Recent Progress and New Trends in Compliance Philosophy," presented at the 17th ICAS, Stockholm, Sweden, 1990.

Standard Test Development

OBJECTIVES

- Develop and validate practical, low cost consensus standard structural test methods.
- Develop consensus design allowables usage guidance for airframe structures, and generic material specifications.

Test Development and Structural Usage Allowables Guidance Activities



Standard Test Development

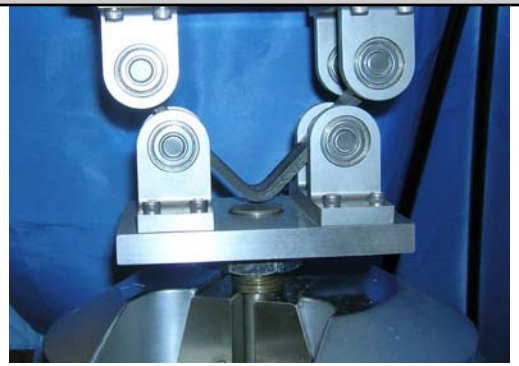
2005 RESULTS:

D5961 (Bearing Tension & Compression)

The revised standard was

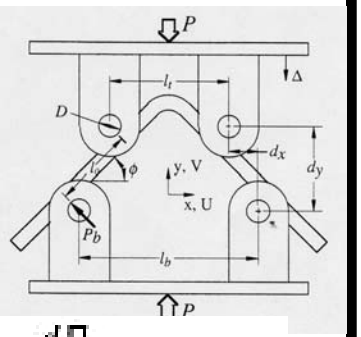
approved

for publication in Jan 2005



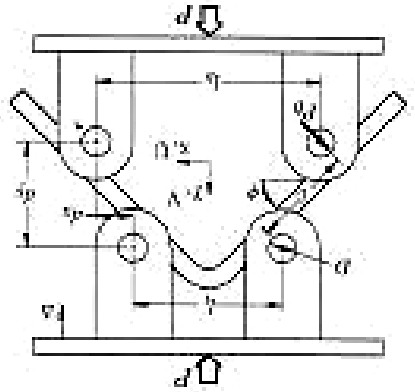
D6415 (Curved Beam Strength & ILT)

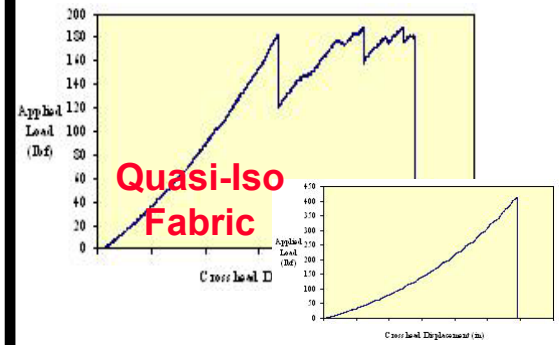
ASTM D6415 Curved Beam Interlaminar Tension Strength

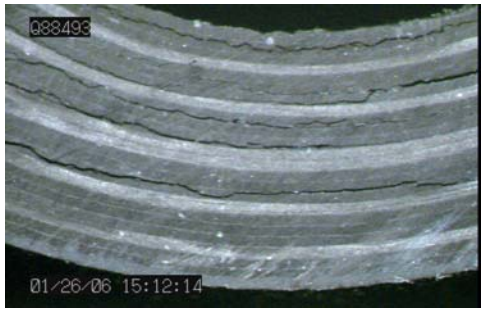


Testing Program

Resin Sys / Lay-ups / Fiber Form	Brittle		Toughened	
	0°	Quasi-Iso	0°	Quasi-Iso
Tape	▪ All carbon/epoxy ▪ 80 specimens were tested			
Weave Fabric				







Findings

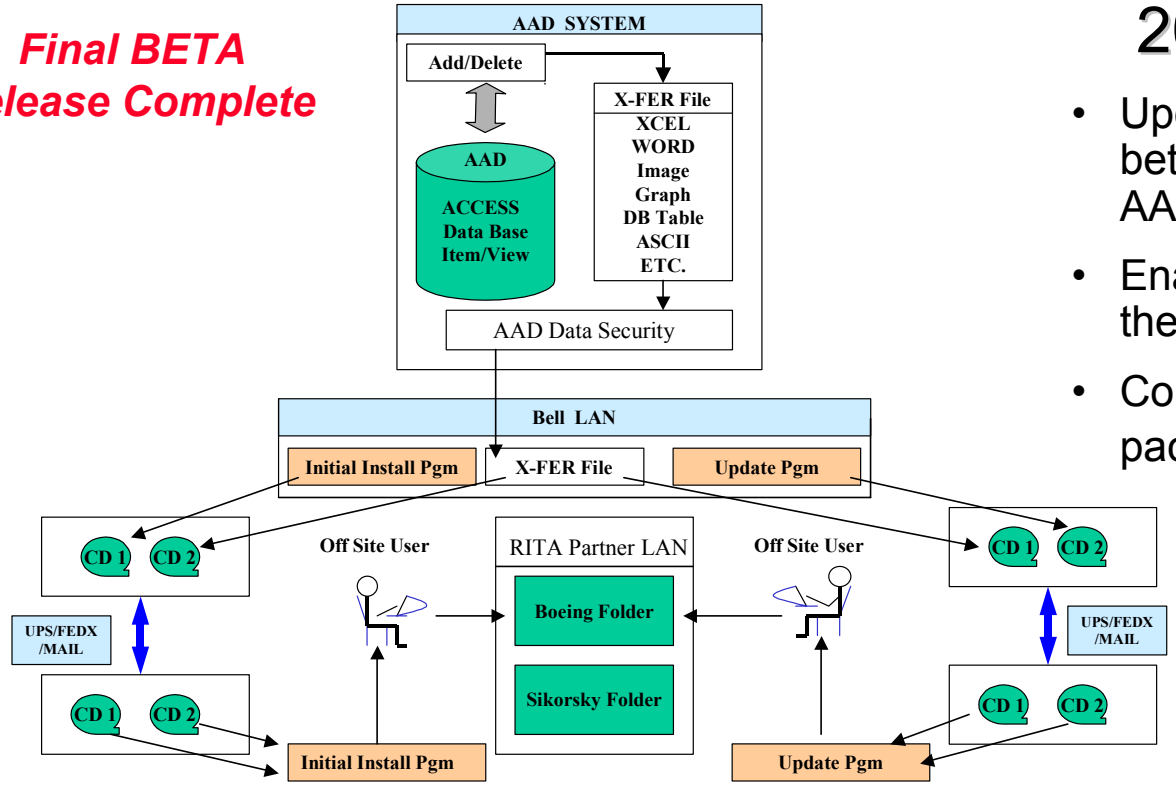
1. Mean ILT strength values
   $[0]_{24}$ > $[(+45/90/-45/0)_3]_S$ | toughened > brittle | tape > fabric
2. Delamination modes
   Single delamination for 0° tape (brittle and toughened)
   Multi-delaminations for the rest
3. Load drop modes
   Multi-load drop for quasi-isotropic fabric
   Single load drop for the rest
4. The test set-up should be upside-down for better alignment !!!

Electronic Database System

OBJECTIVE

Develop an electronic database framework for multi-company material property data sharing.

Final BETA Release Complete



2005 RESULTS

- Updated and finalized the beta version of the secure AAD relational database.
- Enabled periodic update of the database.
- Completed installation package for final version.

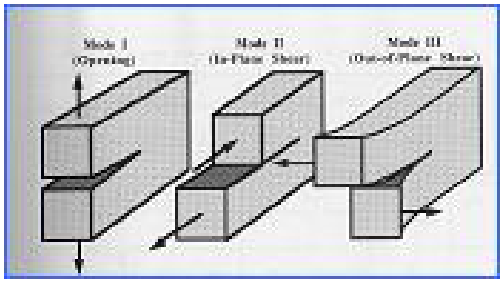
Composite Fatigue Delamination Growth Prediction Methods

Goal: *Develop and validate FE-based composite fatigue/fracture methodology that addresses crack initiation/growth in critical rotorcraft components*

Why? *To enable "virtual testing" of full-scale components prior to structural test to reduce/eliminate potential "gotchas" late in the program*

Steps:

- Standardize test methods for determining material allowables for various modes of crack initiation/growth (Mode I, Mode II, and Mode III) – ASTM D30-06 participation



G_I (static/fatigue) – Mode I
G_{II} (static/fatigue) – Mode II
G_{III} (static/fatigue)– Mode III

- Evaluate existing analysis methods such as strain invariant failure theory (SIFT) (possible method for determining initiation) and interlaminar fracture mechanics (ILFM) (method for evaluating damage tolerance of composite structures in the presence of a delamination/crack)
- Validate analysis methodology on subelements (flexbeams, T-T straps) and full-scale components

Composites Life Methods

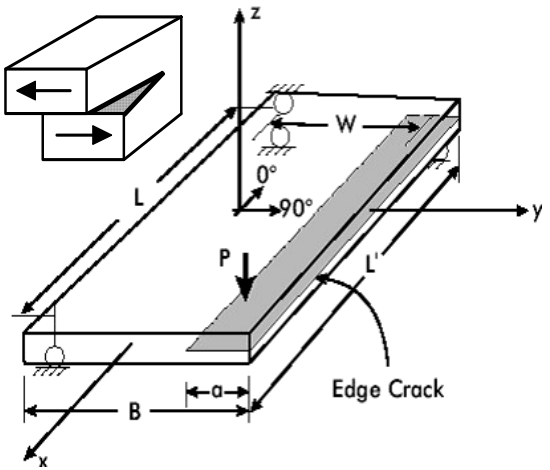
2005 Focus:

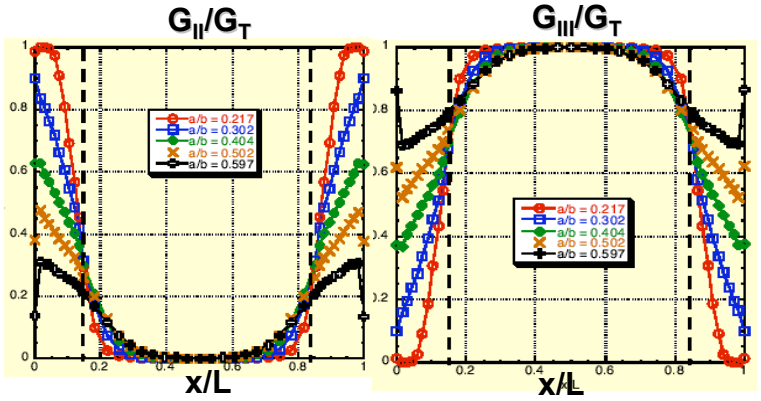
ECT test method for Mode III interlaminar fracture characterization.

Issues to address:

- uneven crack front
- mode II fracture interfering

Mode III ECT





*) Ref: James Ratcliffe

2005 ACCOMPLISHMENTS

- Discussion in Mil-17/ASTM D30 Task Groups
- A work plan on
  (1) micro-failure scenario investigation
  (2) parametrical/experimental analysis for pure mode III
- Creation of parametrical FE models with and without delamination.

Rotorcraft

Operate in Hostile Environments !!!

Composites in Extreme Environments

OBJECTIVE:

- Understand and determine the effects of hostile environments on rotorcraft laminated composite structures
- Establish methodologies to characterize such *H*ostile *Environment Induced D*amage (HEID)

CERTIFICATION REQUIREMENT

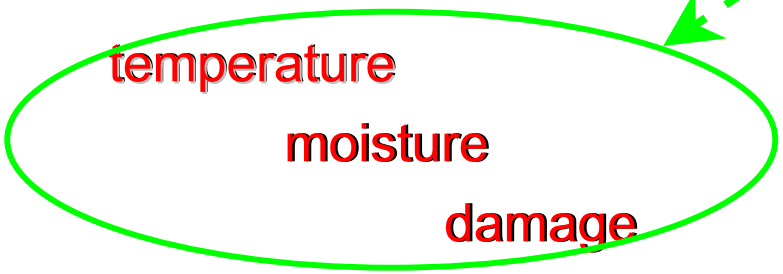
Material Qualification

Characterization of:

- Material properties
- Strength properties
- Durability properties
- Acceptance criteria

Focus of this research

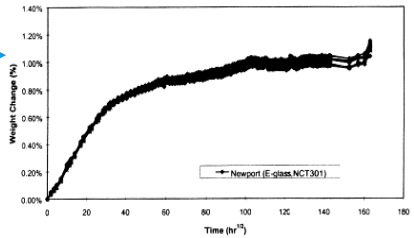
as a function of

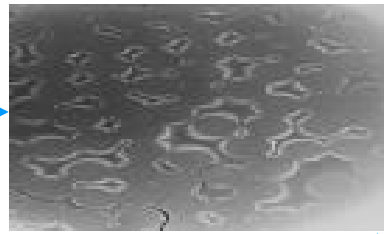


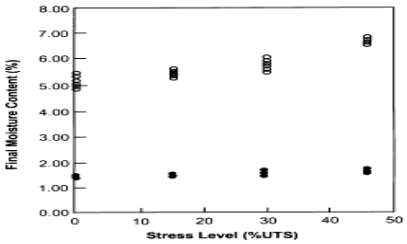
PREVIOUS FINDINGS

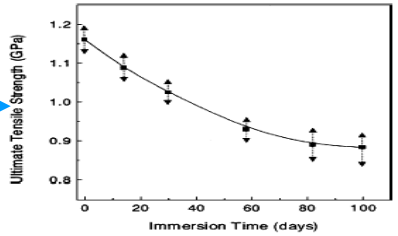
Water absorption and its Effects :

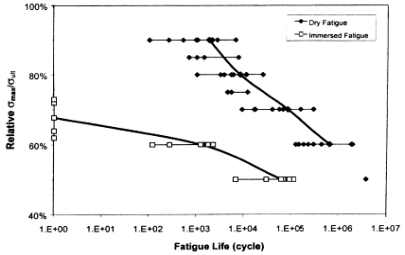
- Composite materials absorb water over time
- Exposure of composites to water causes the matrix cracks
- The increased tensile load accelerates water absorption
- The Ultimate Tensile Strength decreases with exposure
- Fatigue life is shorter for materials immersed in water over time



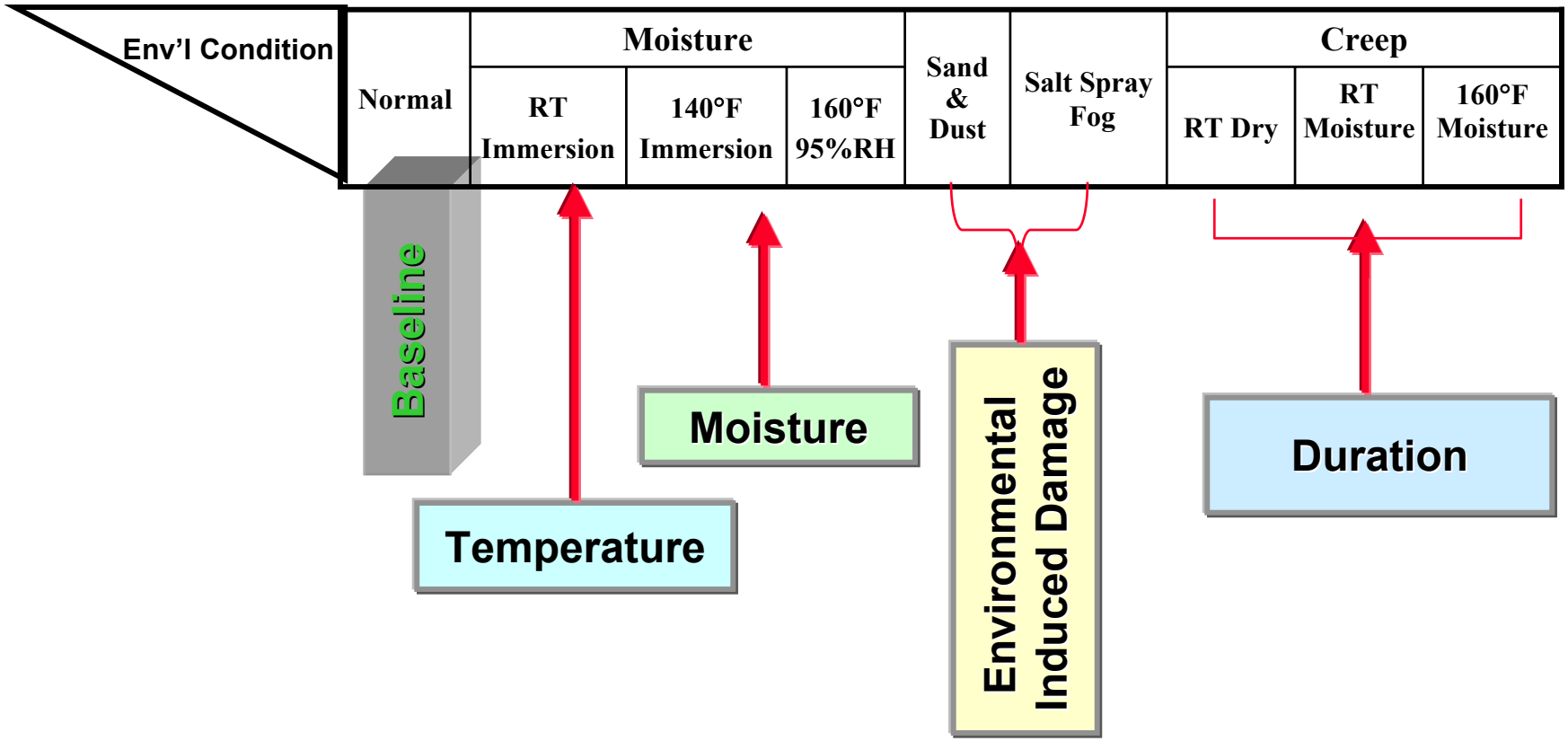








Environments



Material Properties

Environments

Test Item \ Env'l Condition		Normal	Moisture			Sand & Dust	Salt Spray Fog	Creep		
			RT Immersion	140°F Immersion	160°F 95%RH			RT Dry	RT Moisture	160°F Moisture
Tension Unidir'l	Longitudinal									
	Transverse									
Tension Laminate	Angle-Ply									
	Rep C/E,G/E Laminate									
Shear	In-Plane									
	Out-of-Plane									
Flexural Modulus										
Fracture	Mode I									
	Mode II									
	Mode III									

Primary Interest

Transverse Tension & Angle Ply

Shear: In-Plane, Out-of-Plane

Fracture

Composites in Extreme Environments (cont)

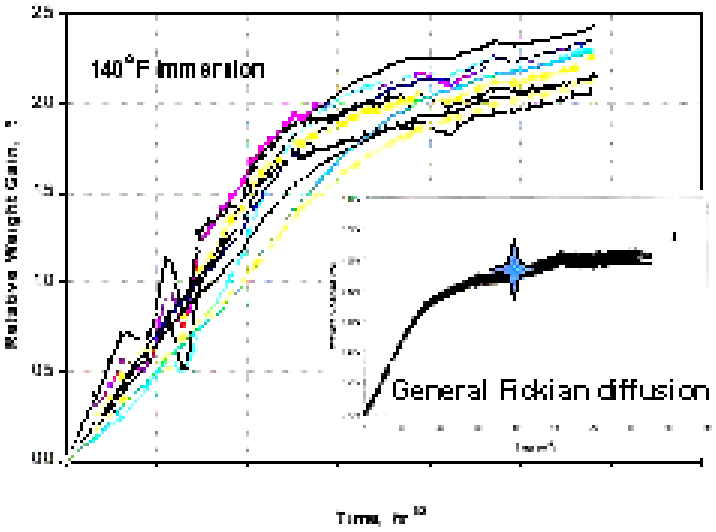
Test Matrix – Project Plan

Test Item / Env'l Condition		Normal	Moisture			Sand & Dust	Salt Spray Fog	Temperature		
			RT Immersion	140°F Immersion	160°F 95%RH			RT Dry Creep	RT Moisture Creep	350°F Moisture Creep
Tension Unidir'l	Longitudinal	Begin in 2006						2005 Begin in 2005		
	Transverse	2004	Immersion Began in 2004			2004				
Tension Laminate	Angle-Ply									
	Rep C/E,G/E Laminate									
Shear	In-Plane		Testing Begin in 2005							
	Out-of-Plane									
Flexural Modulus										
Fracture	Mode I							N/A		
	Mode II	Begin in 2006								
	Mode III									

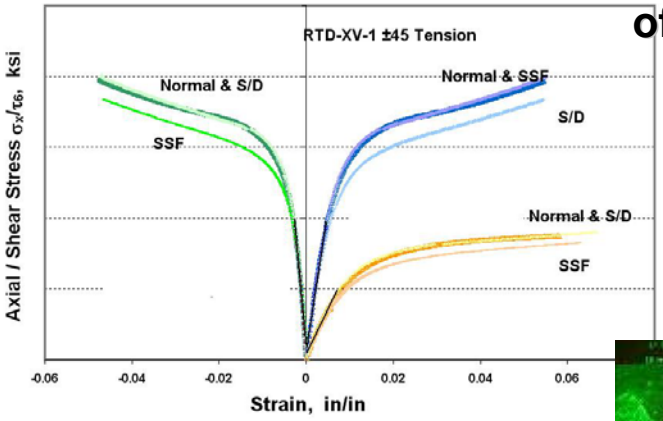
ACCOMPLISHMENTS

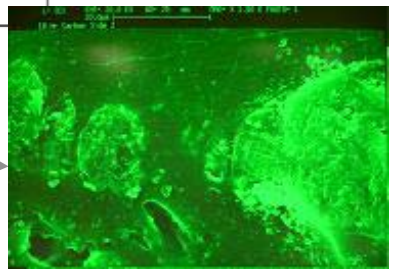
Water Absorption

- Continued water absorption observation in 3 conditions.
- 14000 exposure-hour weight gain data.



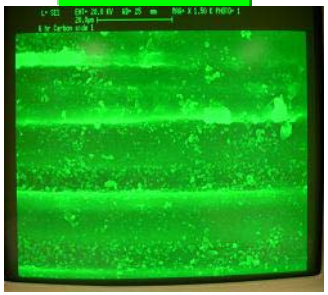
Environmental Effects on mechanical response of R/C composites

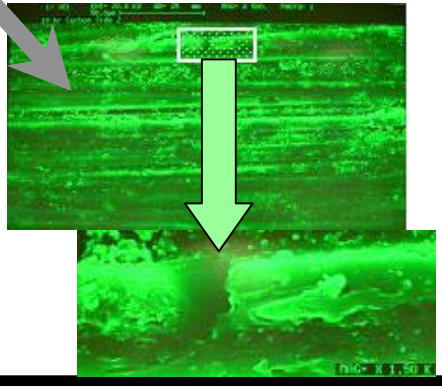




After

Before

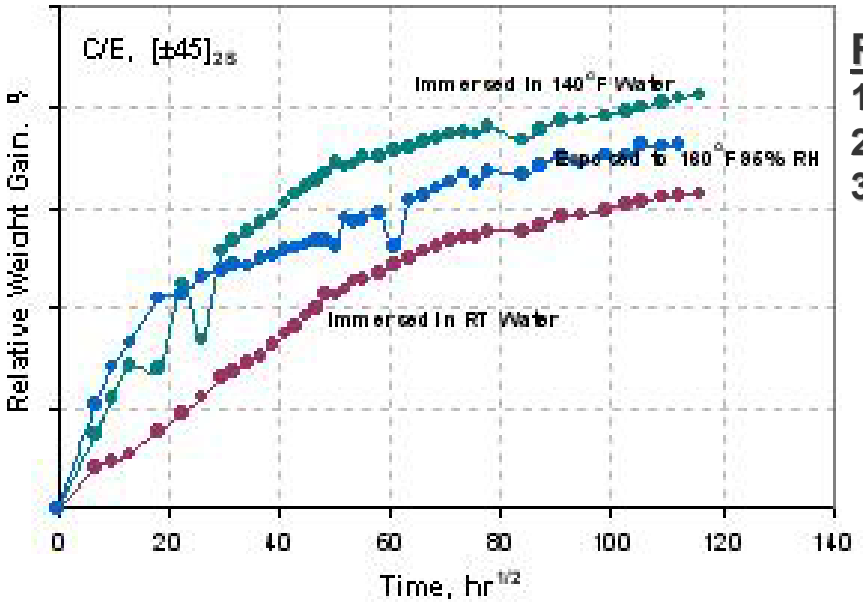




Effects of Sand and Dust

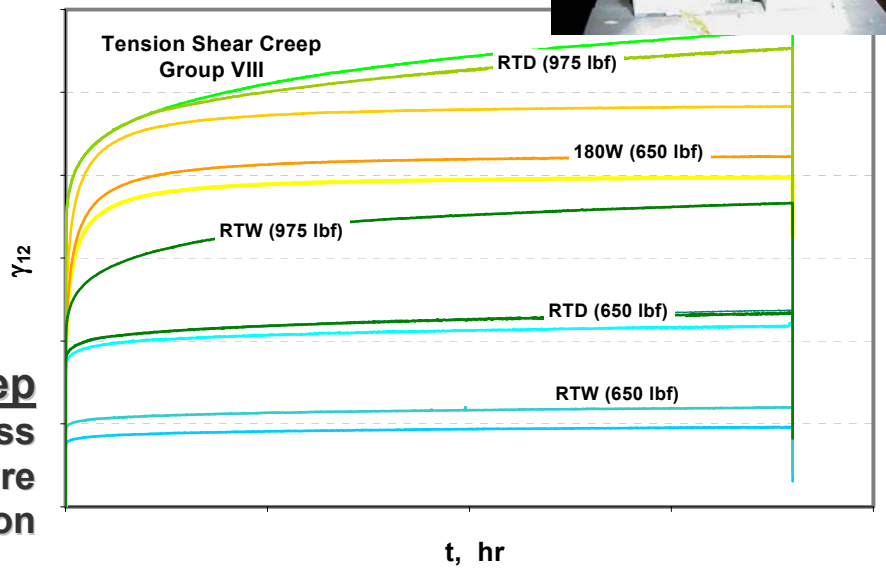
Composites in Extreme Environments

Findings



Rank of Envt'l Effect on Weight Gain

1) 140°F immersion
2) 160°F 95%RH
3) RT immersion



Rank of Envt'l Effect on Creep

1) Stress
2) Temperature
3) Moisture Condition

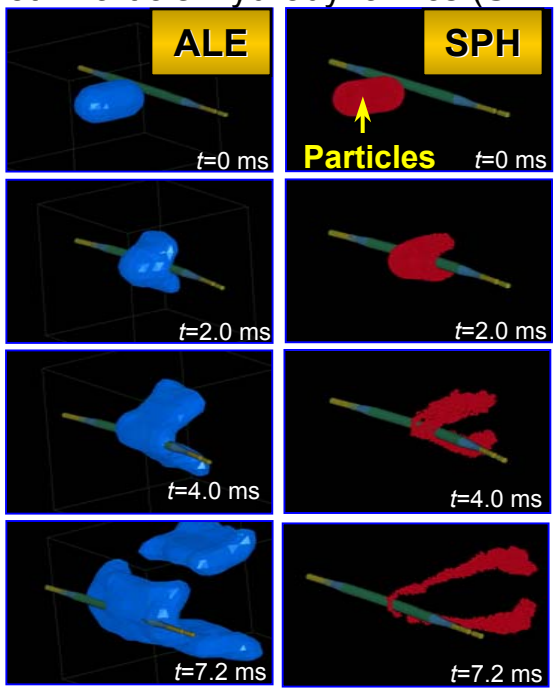
Crashworthiness

OBJECTIVE: Develop analysis capabilities to accurately predict –

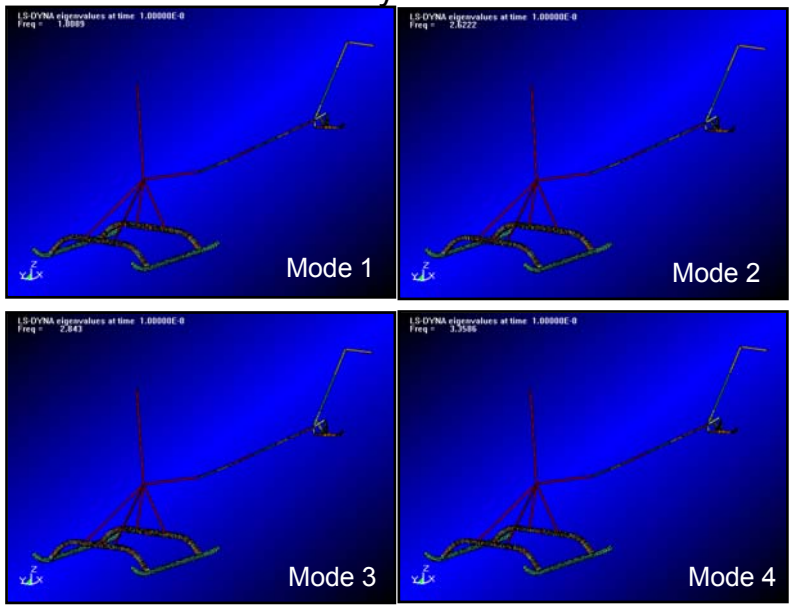
1) Structural response to bird strike
2) Frequency and damping of skid landing gear ground resonance

ACCOMPLISHMENTS

LS-DYNA simulation of bird strike using Arbitrary Lagrangian-Eulerian (ALE) and Smooth Particle Hydrodynamics (SPH)



LS-DYNA skid landing gear model for eigenvalue and time domain ground resonance analysis



LS-DYNA Mode Shapes

Summary

- **Structural Test Development & Allowables Usage Guidance**
  - Approved ASTM D5691 for publication.
  - Updating ASTM D6415 test methods.
- **Electronic Structural Properties Database**
  - Updated and finalized the beta version of the secure AAD relational DB, and associated GUI.
- **Composite D&DT Methods**
  - Development of testing method for characterizing interlaminar mode III fracture toughness. ANSYS macro code for parametrical analysis of mode III ECT configuration. Test plan has been created.
- **Composites in Extreme Environments**
  - Moisture conditioning continues. The exposure time has reached 14,000 hours.
  - Creep testing coupons were fabricated and tested in three environmental conditions.
- **Crashworthiness**
  - Developed techniques for simulating bird strike using both Arbitrary Lagrangian-Eulerian (ALE) and Smooth Particle Hydrodynamics (SPH) techniques in LS-DYNA.
  - Demonstrated feasibility of using explicit technique in LS-DYNA to predict frequency and damping for landing gear resonance analysis in time domain.